Space Medicine Introduction

USAFSAM Aerospace Medicine Primary

June 2016

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DoD-NASA Aerospace Medicine Liaison Officer

Background

- Kirksville College of Osteopathic Medicine (now A.T. Still University)
- Botsford General Hospital: Family Medicine
- USAFSAM: RAM X
  - Aerospace Med
  - Occ Med
- DoD Aerospace Medicine Liaison to NASA

Brief Service History

- Minot AFB – Family Med / Lead PRP
- Kunsan AB – Flight Med CC
- Geilenkirchen NATO AB – Chief, Aeromedical Services
- RAM X
- Minot AFB – SGP
- Ramstein AB – USAFE/AFAFRICA SGPA
- Johnson Space Center – DoD Aerospace Med Liaison to NASA

Objectives

- Recognize the major hazards of spaceflight to astronauts
- Identify the major physiological adaptations in spaceflight
- Appreciate the range of medical operations issues that Flight Surgeons address

Working at NASA

What my parents think I do.

What my friends think I do.

What my kids think I do.

What the government
thinks I do.

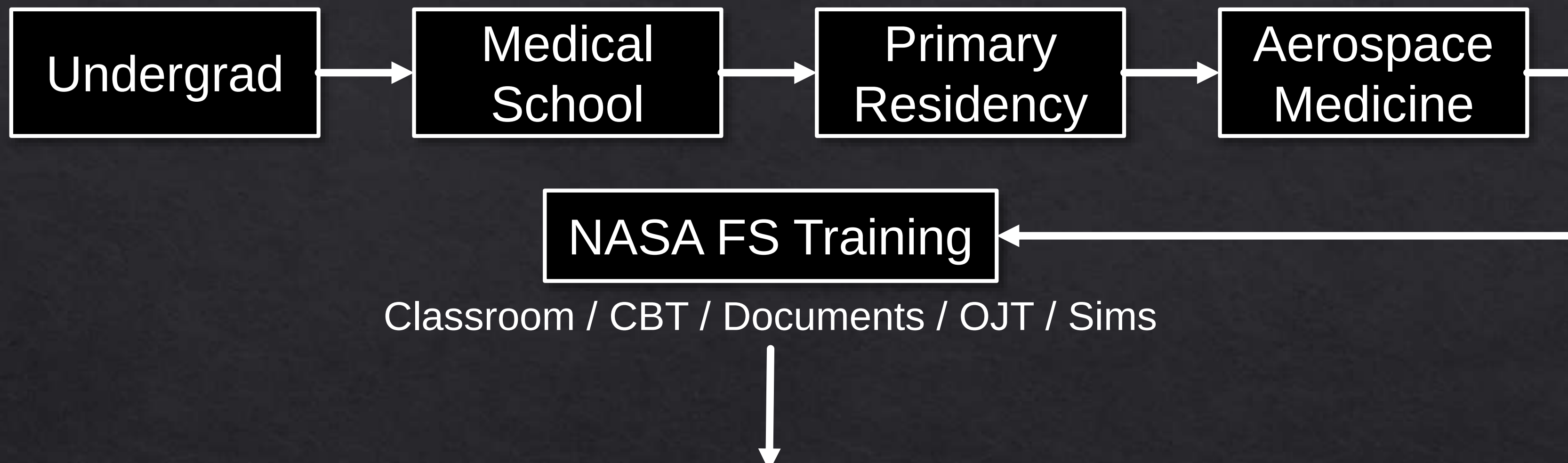
What I think I do.

What I actually do.

What do NASA Flight Surgeons do?

Provide the medical support necessary for astronauts to perform their required duties to assure mission success

More About NASA Flight Surgeons



- FCR-1 SURGEON
- Mission support
- Selection and certification
- Additional administrative duties (e.g., Training, HMS, Flight Rules, Commercial Crew, Exploration)

ASCRs

Behavioral Health & Performance

Radiation

Clinical Consultants

"Nuts and bolts"

"Blood and guts"

Nutrition

Toxicology

Acoustics

Payloads

Physiology

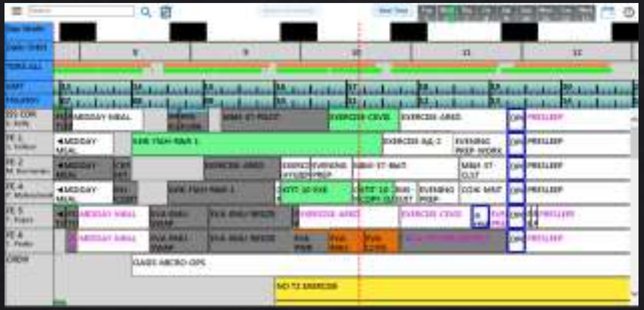
IP Counterparts

Microbiology

HAZARDS OF SPACEFLIGHT

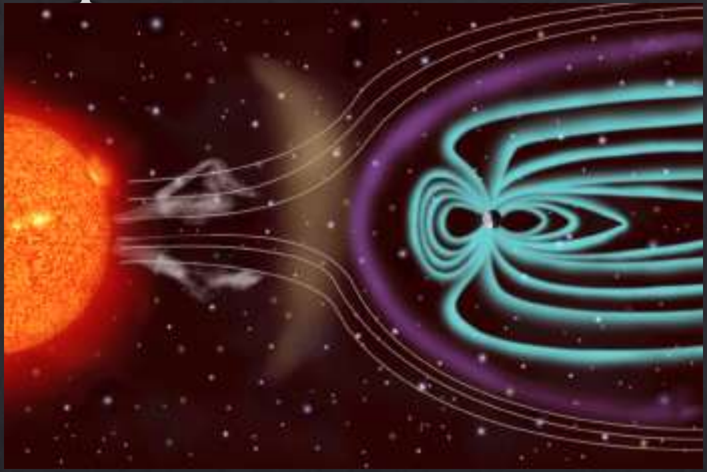
Space Environment

Spacecraft Environment



Spaceflight Mission

Space Radiation



- Three main sources
  - Galactic cosmic radiation
  - Trapped Radiation
  - Solar particle events
- Exposure based on orbital altitude/inclination, duration, and solar activity
- Astronauts are radiation workers

Galactic Cosmic Radiation (GCR)

- Originates outside the solar system
  - Most likely from supernova explosions
  - Primarily H nuclei (90%), rest mostly alpha or He nuclei
- Flux from GCR is low but energy is massive
  - A single GCR particle at the very high end of the spectrum (1.5×10^{20} eV) carries 25 joules, enough to raise 1 kg to 2.5 m height on earth
  - Highest levels in open magnetic field areas
  - Very Penetrating; Hard to Shield

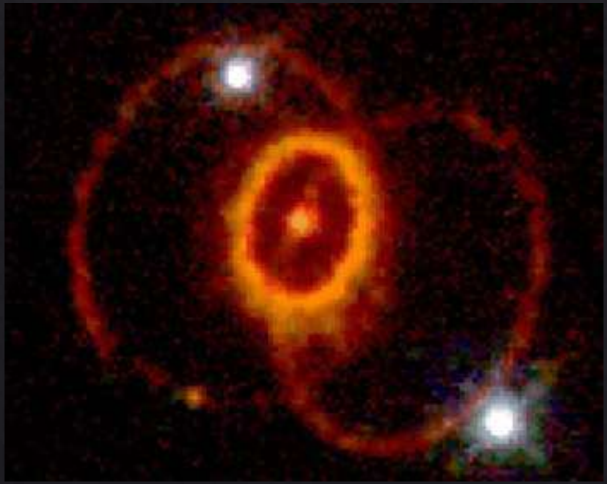


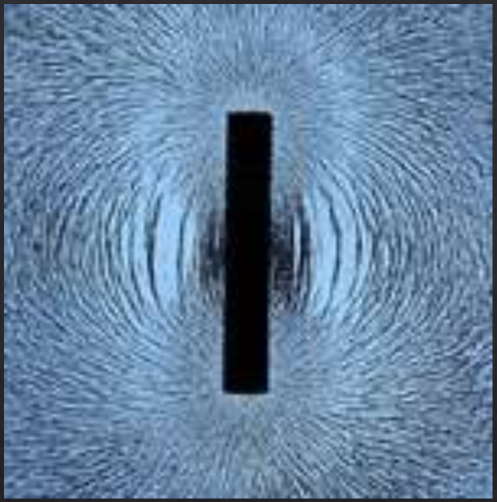
image from NASA/HST

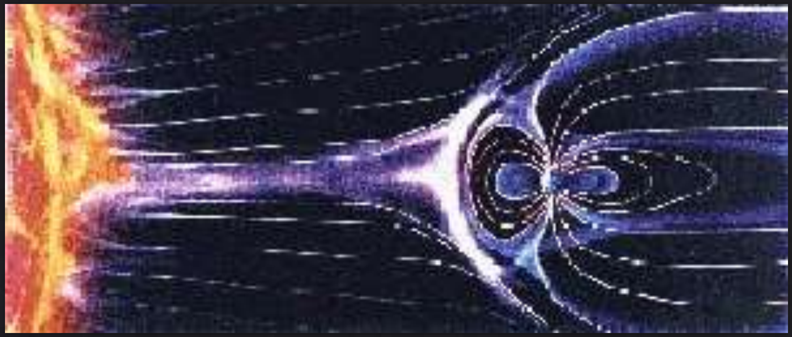
GCR Continued

- Modulation varies with solar cycle (22 years) so that at solar max, the GCR bathing earth is about ½ the flux at solar min.
  - GCR is attenuated by Earth atmosphere, which has thickness of 1000 g/cm^2 and by powerful geomagnetic fields.
  - Particles with > 10 GeV aren't affected as much by solar wind / magnetic fields
- Biologically Most Damaging

Geomagnetic Field

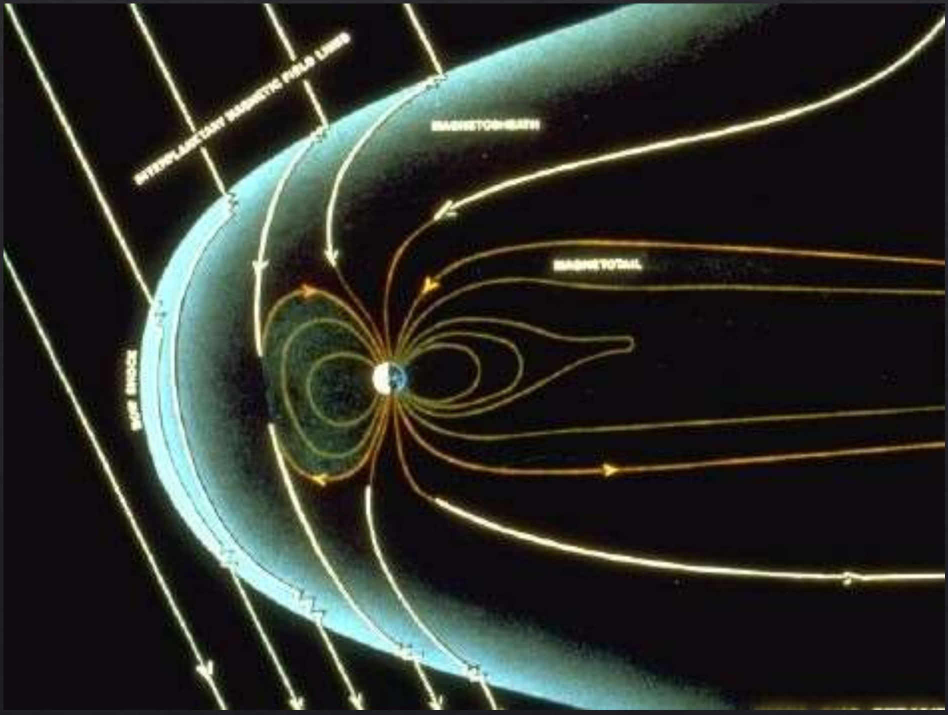
- Rotation of Earth's molten iron core creates electrical currents, producing a magnetic field
  - Similar to a common bar magnet
  - Field extends several thousand Km
- The sun produces solar wind
  - Primarily protons and electrons
  - Compression of the field by this wind forms the protective magnetosphere





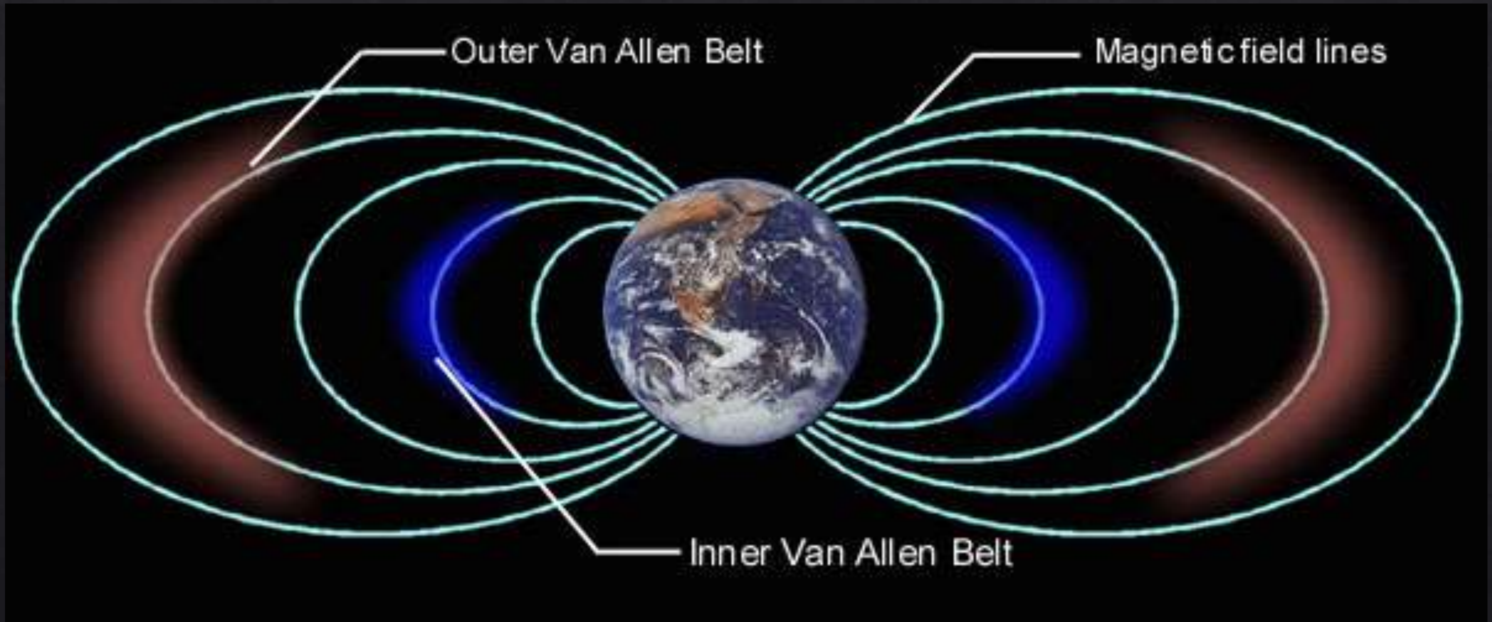
Geomagnetic Field and Trapped Radiation

- Closed field lines shield the Earth from radiation
- Open field lines at poles
  - Allow radiation to penetrate to low altitudes
  - Auroras
- Traps radiation within the belts
- 11^{o} shifted and off-set by 500 km
- South Atlantic Anomaly
  - Region where the inner proton belt dips into the lower atmosphere (200 km)

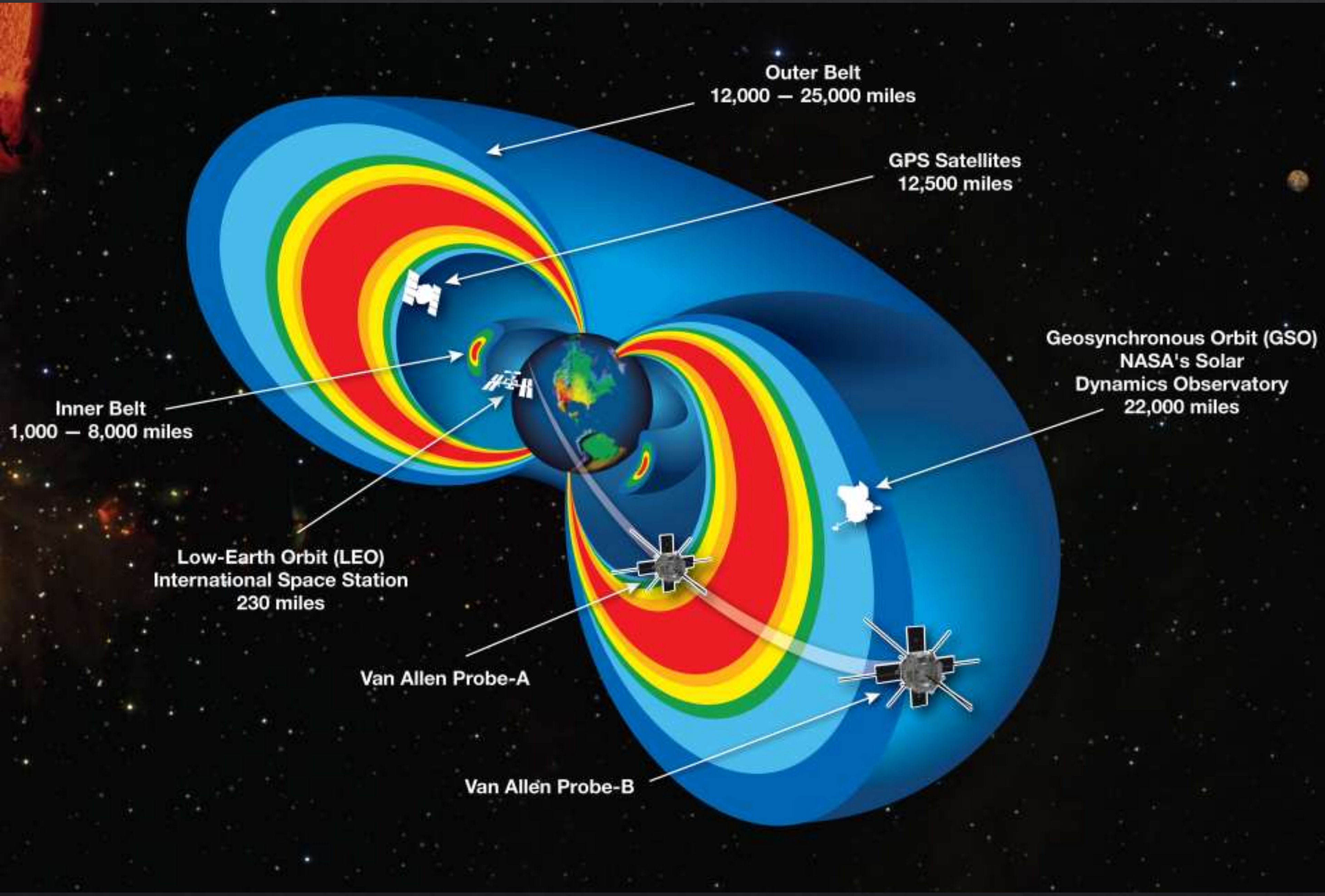


Van Allen Belts

- In 1958, the first successful US Satellite, Explorer I, brought a Geiger counter devised by James Alfred Van Allen.
  - Van Allen belts are arranged as two concentric doughnuts centered on the geomagnetic equator.
  - Charged species populating the Van Allen belt are essentially captured particles from solar wind and solar cosmic rays.



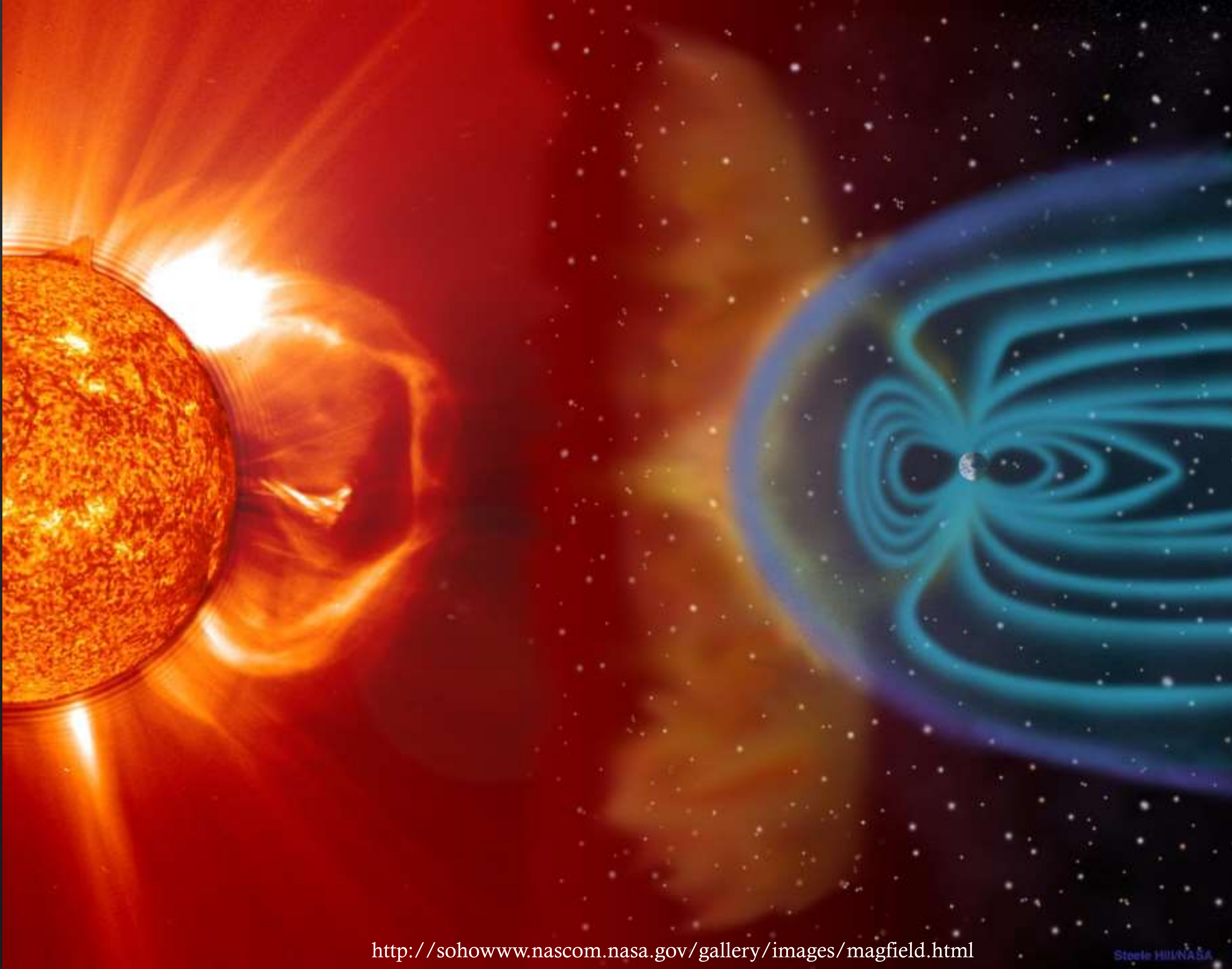
Van Allen Belts



Inner and Outer Belt

- Inner belt protons are most likely from interaction of GCR with asmostphereic species, forming short lived neutrons.
  - Some decay into protons / electrons, which are then bound.
  - Typically high energy with protons of 50 MeV and electrons of 30 MeV.
- Most human platforms in LEO are well below the floor of the belt.
  - Spacecraft with alt of 225 km have 100x increase in radiation flux in SAA
  - At 440 km, its 1000x.

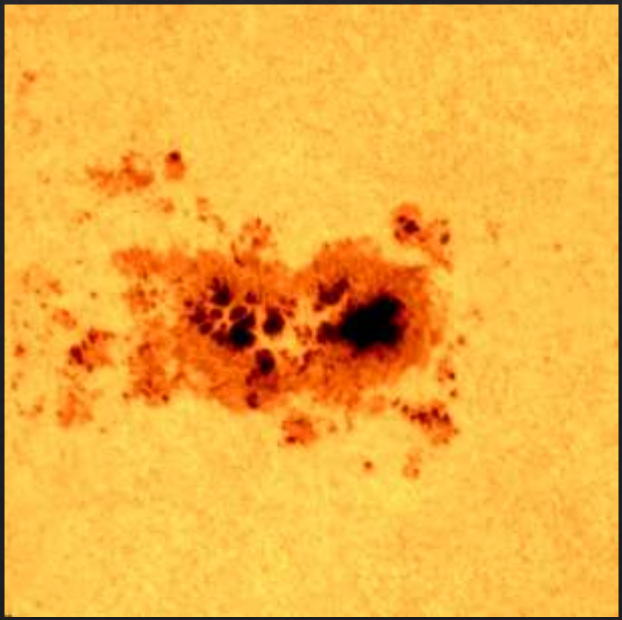
- Outer belt particles originate from the interaction of solar wind with magnetosphere.
  - More susceptible to dynamic effects of solar wind and SCR.
  - Mostly electrons



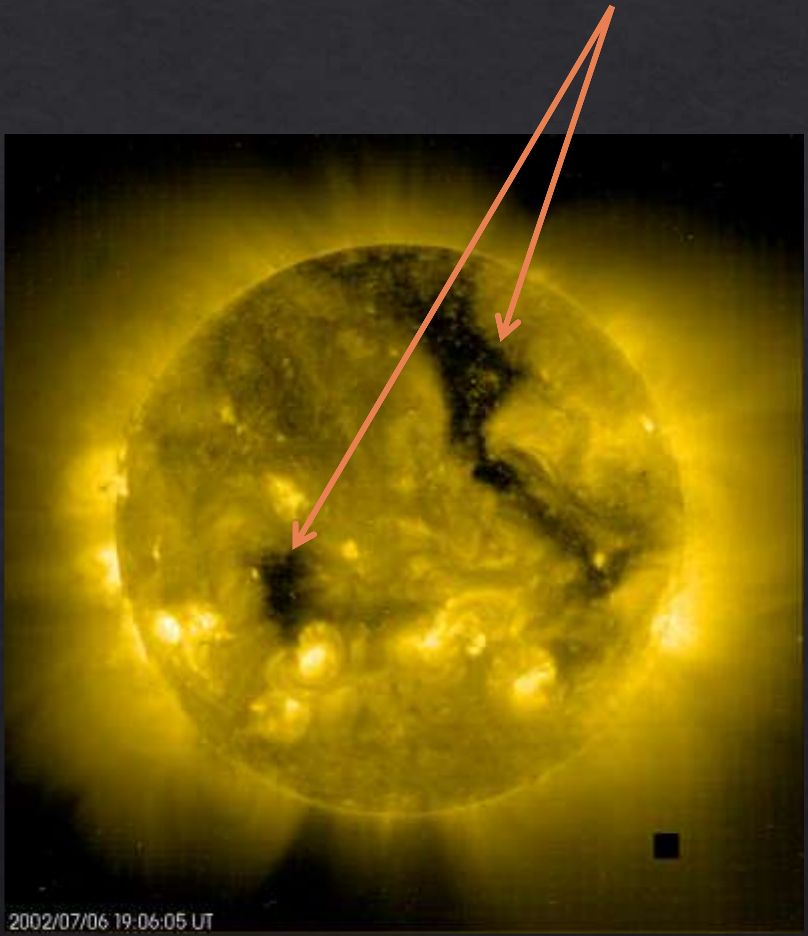
http://sohowww.nascom.nasa.gov/gallery/images/magfield.html

Solar Weather and Radiation

- Solar events:
  - Solar Flare
  - Coronal Mass Ejection (CME)
  - Solar Energetic Particle Event (SEP)
- Solar cycle
  - Average 11 years
  - Magnetic filed polarity reverses during every solar cycle
- Active Regions
  - Regions where negative and positive field become entwined
  - Sunspots: Cool regions with increased magnetic activity



Coronal Holes

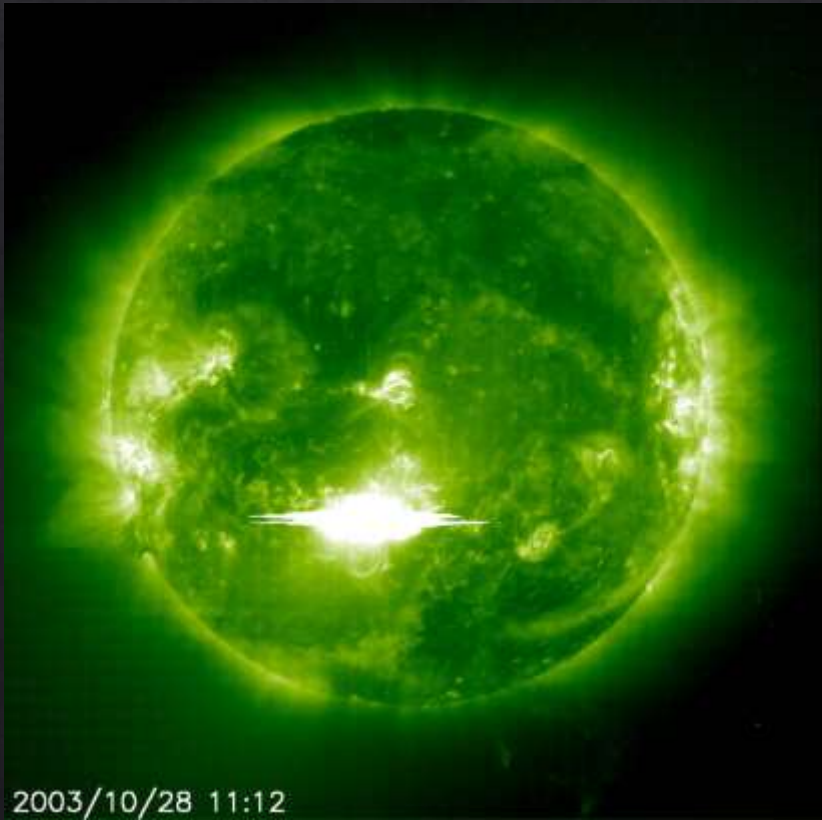


- Magnetic Field Open to Space
- Continuous release of energy
- May cause geomagnetic disturbances

images from SOHO/NASA

Solar Flares

- No direct impacts [to crew] - only an indication of energy release
- Highly concentrated explosive release of X-ray energy
- Happens frequently
- Major events (SEP or CME) are preceded by a flare



Coronal Mass Ejection (CME)

- The release can be observed and determined if Earthbound
  - Takes 1 to 3 days to arrive
  - Increases region area of high risk orbital alignment – low magnetic cutoff (poles)
- Causes Geomagnetic storms:
  - Magnetic field disturbances alter electron belt location and intensity
  - Create auroras and move them to lower latitudes
  - Alters low cutoff zones
- EVA hazard

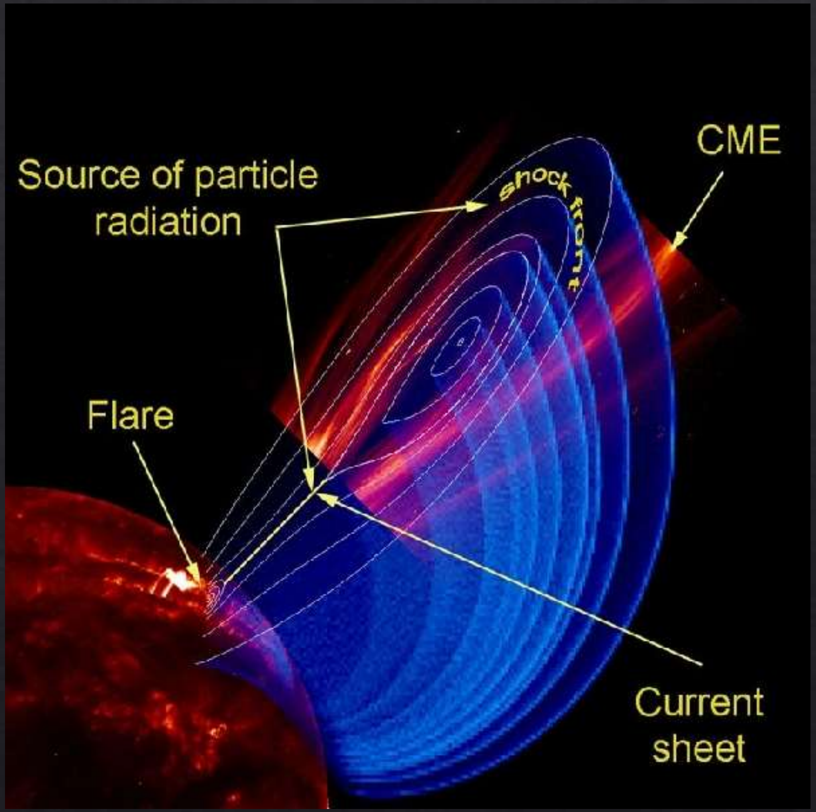
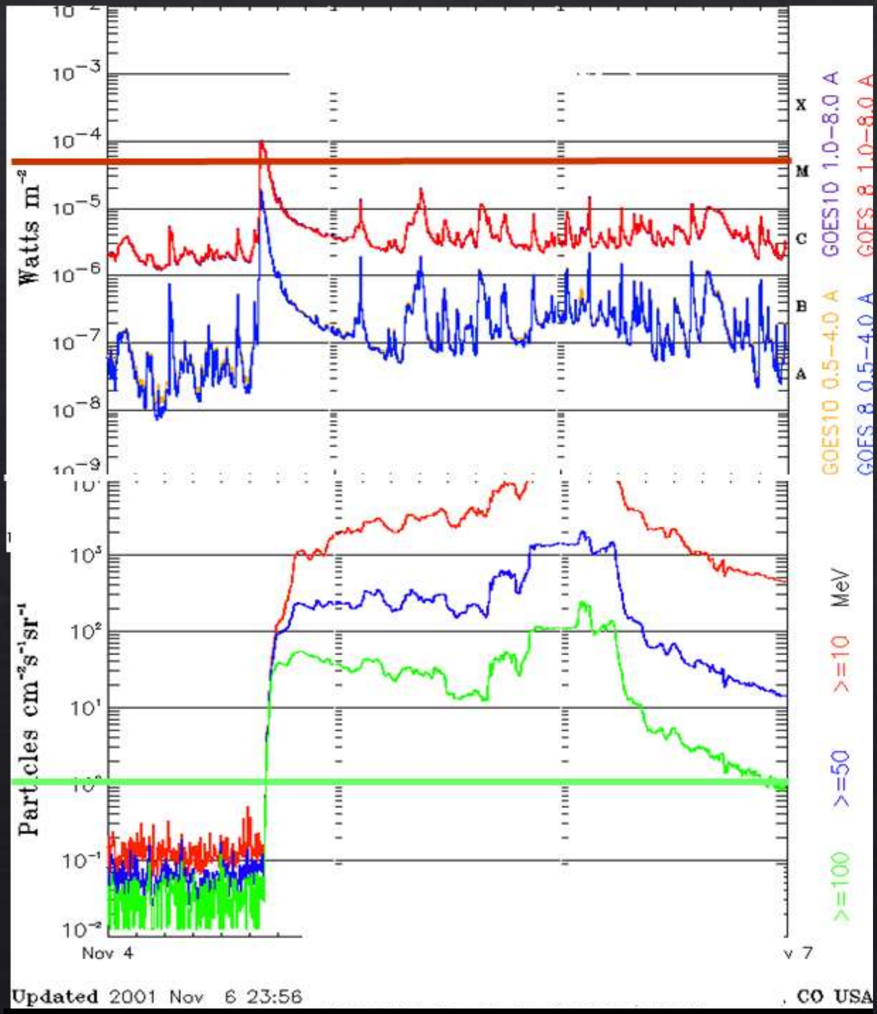


Image taken from sohowww.nascom.nasa.gov

Solar Energetic Particle Events

- About 1% of CME's deliver SEP events
  - High flux levels of protons
  - Arrival times between minutes to hours. Typically average ~ 30 minutes
  - High proton energies up to 1000 MeV
    - >10 MeV to get inside EVA suit
    - >100 MeV to get inside spacecraft
- Energetic proton events are not predictable..
  - Once an event begins, it is difficult to project how the event will evolve..
- In LEO, Trajectory and timing will influence the total exposures. Intermittent exposures
- In free space, no geomagnetic shielding means constant exposure to a proton event

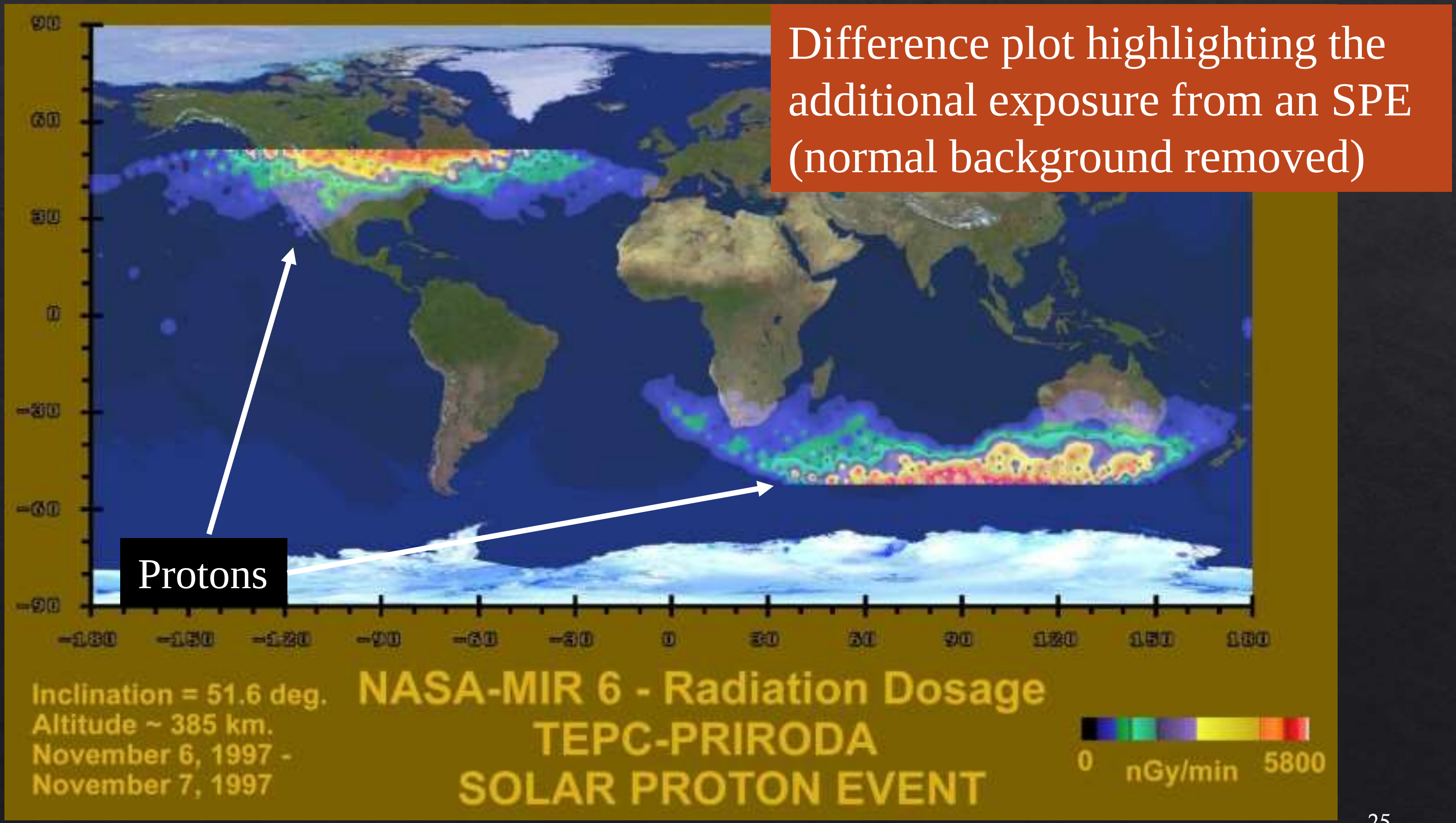
Solar Particle Events



Horizontal lines (red & green) are alarm/action levels

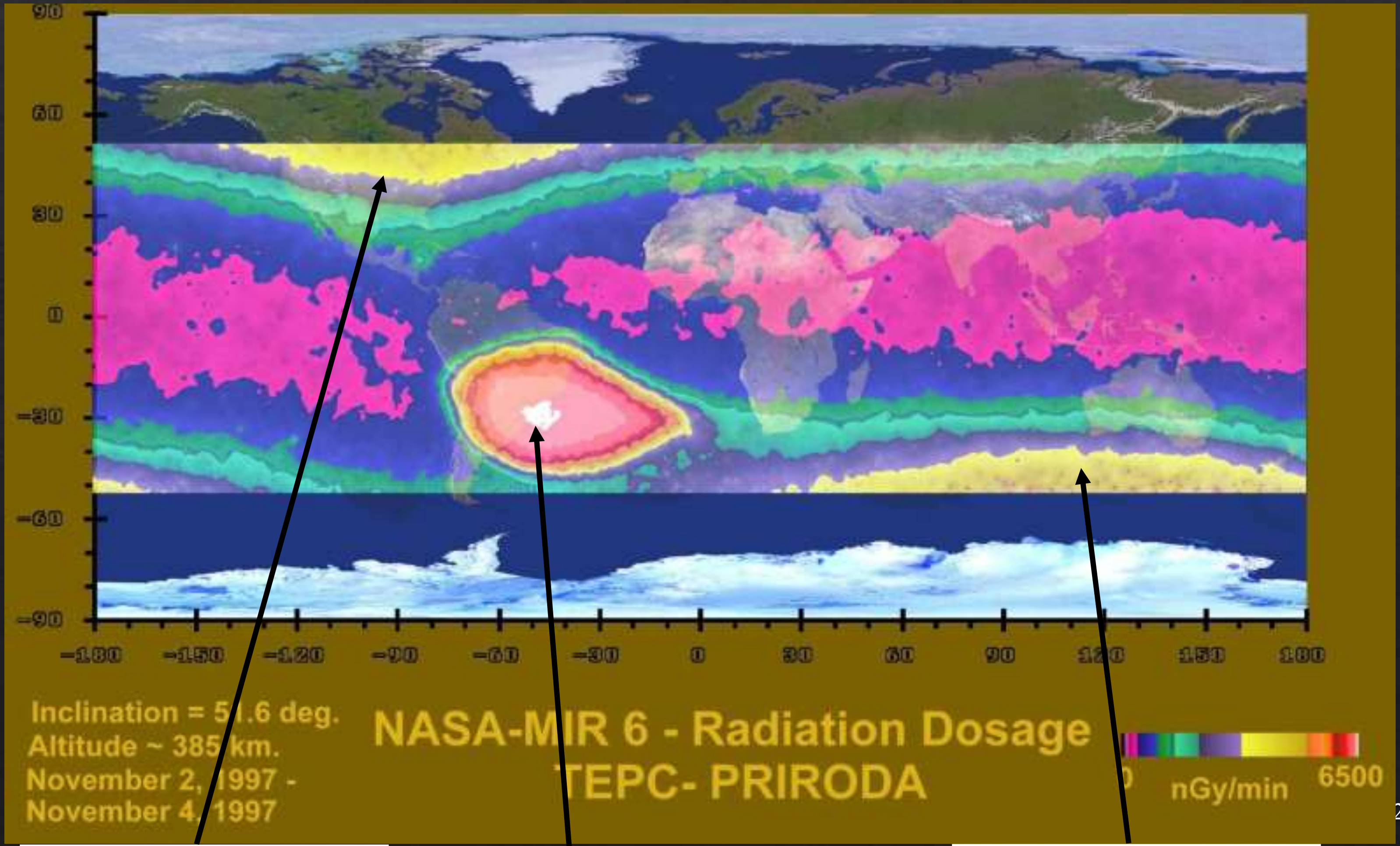
images from SOHO/NASA

Effects at Earth



Protons enter at low cut-off zones
These zones get larger (extend equator-ward) during geomagnetic storms

Effects at Earth



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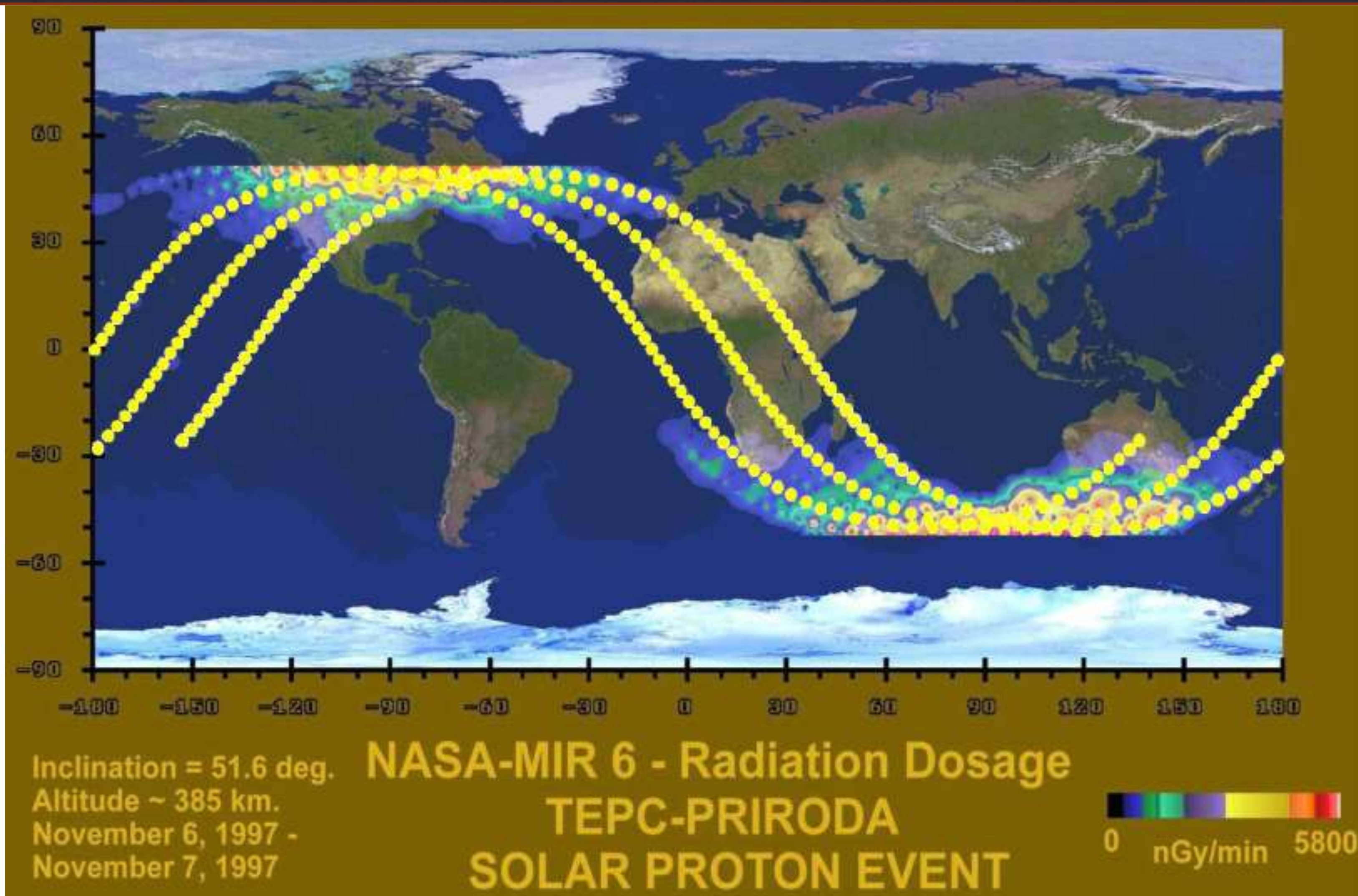
Low Cut-off Zones

SAA

Mir TEPC data

Low Cut-off Zones



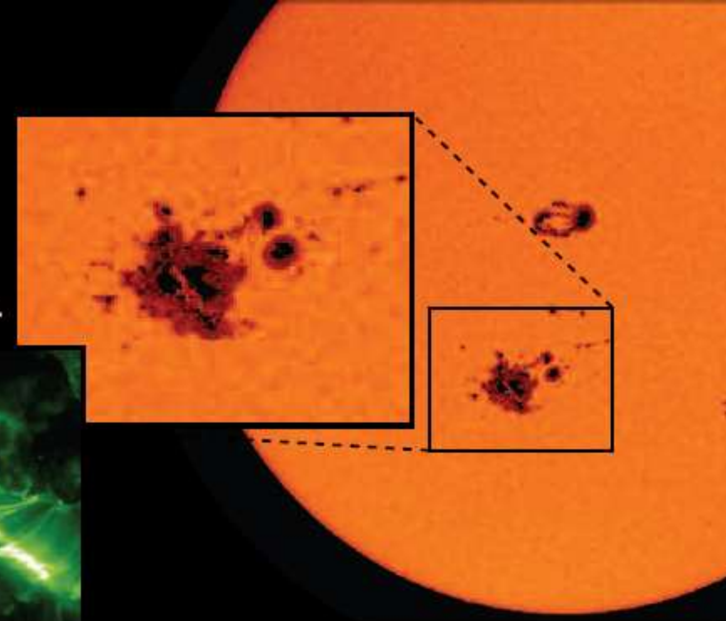
90
60
30
0
−30
−60
−90
−180
−150
−120
−90
−60
−30
0
30
60
90
120
150
180
Inclination = 51.6 deg.
Altitude ~ 385 km.
November 6, 1997 -
November 7, 1997
NASA-MIR 6 - Radiation Dosage
TEPC-PRIRODA
SOLAR PROTON EVENT
0
nGy/min
5800

Effects at Earth

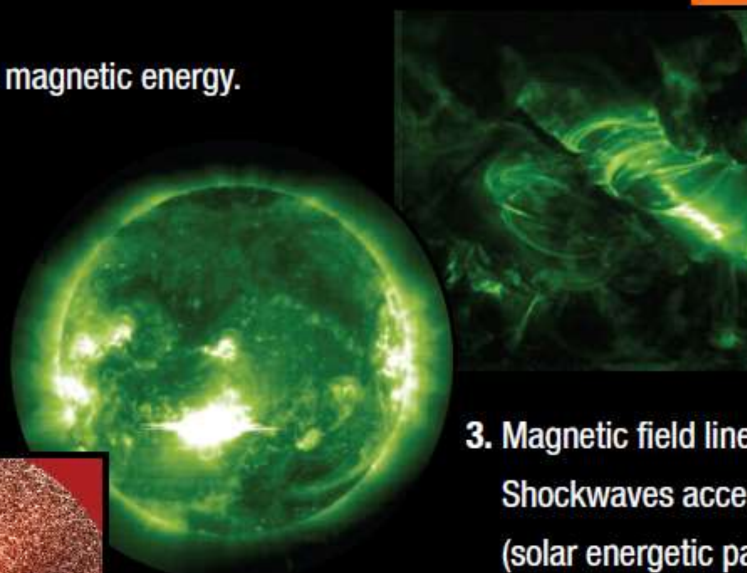
- Geomagnetic storms
  - Compresses the closed magnetic field lines
  - Enhances the electrons in the outer electron belt
- Solar Proton Events
  - Potentially delivers high flux levels of protons
  - Potential hazard to crew and equipment
- Solar cycle effects
  - Solar min
    - Less protection against galactic cosmic radiation
    - Higher trapped radiation levels
  - Solar max
    - More protection against galactic cosmic radiation
    - Lower trapped radiation levels

Anatomy of a Large Solar Energetic Particle Event

1. A collection of sunspots grows into an active region, intertwining magnetic fields.

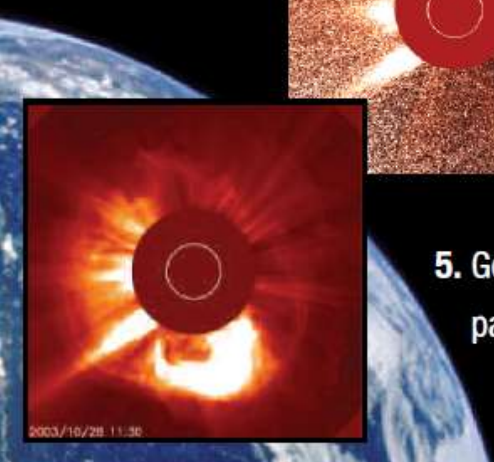


2. Magnetic fields grow and store magnetic energy.



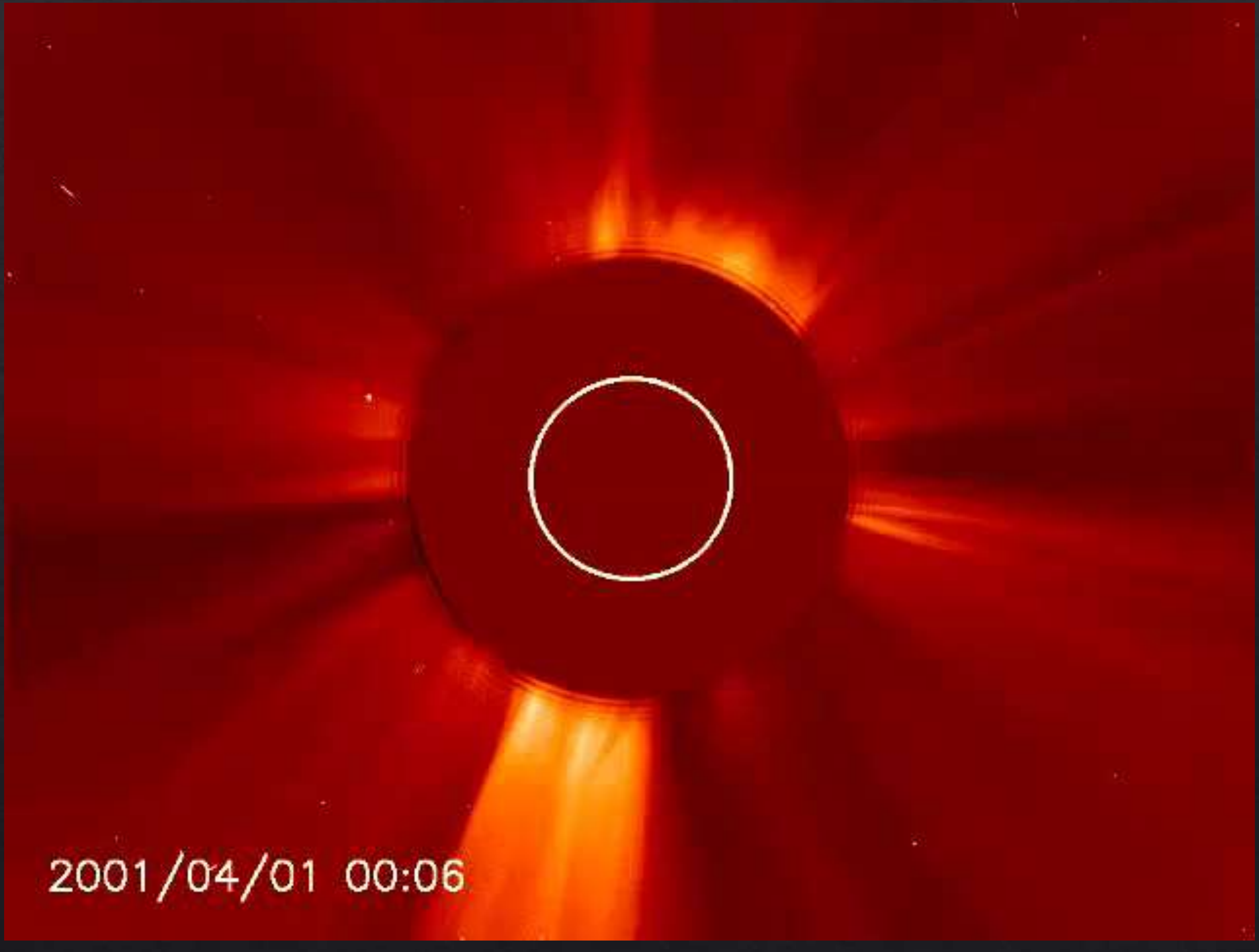
3. Magnetic field lines realign, releasing stored magnetic energy. Shockwaves accelerate charged particles to very high energies (solar energetic particles) and eject an expanding cloud of coronal material away from the sun (coronal mass ejection).

4. The most energetic protons can arrive in minutes. Charged particles hitting a satellite camera create the image of "snow."



5. Geomagnetic storms develop as the coronal mass ejection shock passes Earth 1 to 2 days later.

CME with Proton Shower, LASCO C2 (April 1-27, 2001)



Radiation Exposure Career Limits

- Career limits are established to manage risks associated with radiation exposure, primarily stochastic effects.
  - Primary basis of Career Limits is cancer mortality.
  - Career limits are set to maintain lifetime excess cancer mortality to less than 3%
- Recommendation from National Council on Radiation Protection and Measurements (NCRP) Subcommittee 75 in NCRP Report 98 (1989)
  - NCRP Report 132 (2000), (if you read one, read this one)
  - Additional limits are set for Eye (cataract induction) and Skin. (Deterministic effects)

Radiation Exposure Career Limits

- 3% additional CA mortality risk limit explained
  - To allow for biodiversity and to assure 95% CI, NASA technically uses 1.15%
  - This only includes occupational exposures
  - Any medical, recreational, etc exposure doesn't count toward NASA's limit

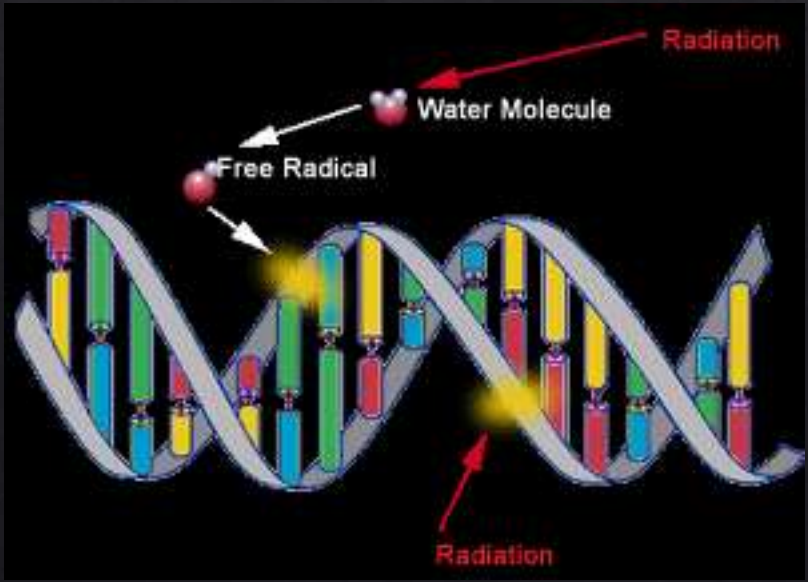
Annual and 30 day limits serve to protect against deterministic effects

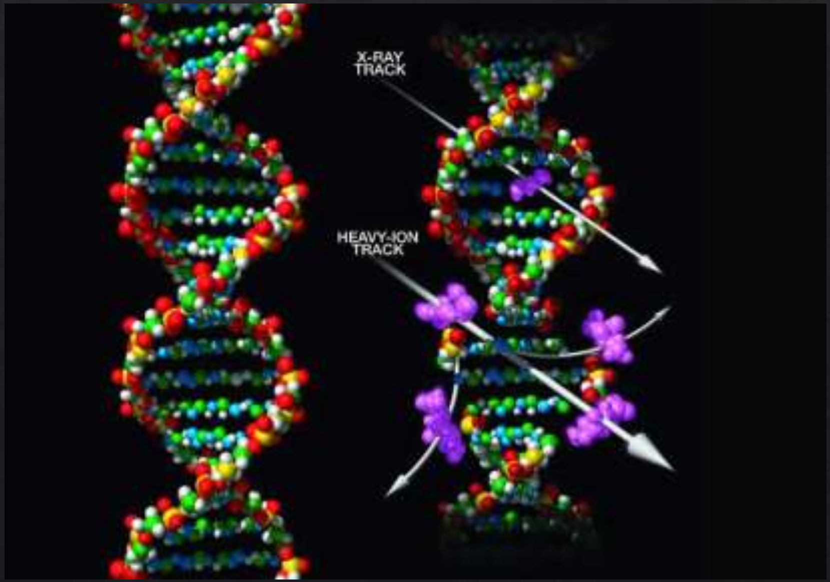
Radiation Dose Ranges

	Typical Dose (rem)
Round-trip NY to London / Chest x-ray (1 film)	0.01
Natural background radiation per year	0.3
CT scan	3-10
Typical mission dose on ISS	**10-15**
Estimated dose for 3-yr Mars mission	100-150
Atomic bomb survivors	Up to 400
Human LD_{50}, no medical intervention	350-550
Human LD_{50}, with medical intervention	500-1000

DNA with Radiation Hit

- Mechanisms of DNA damage
  - Water in the body absorbs a large portion of the radiation and becomes ionized to form highly reactive, water-derived radicals. The free radicals then react with DNA molecules causing the breaking of chemical bonds or oxidation.
  - The radiation collides with the DNA molecule directly.

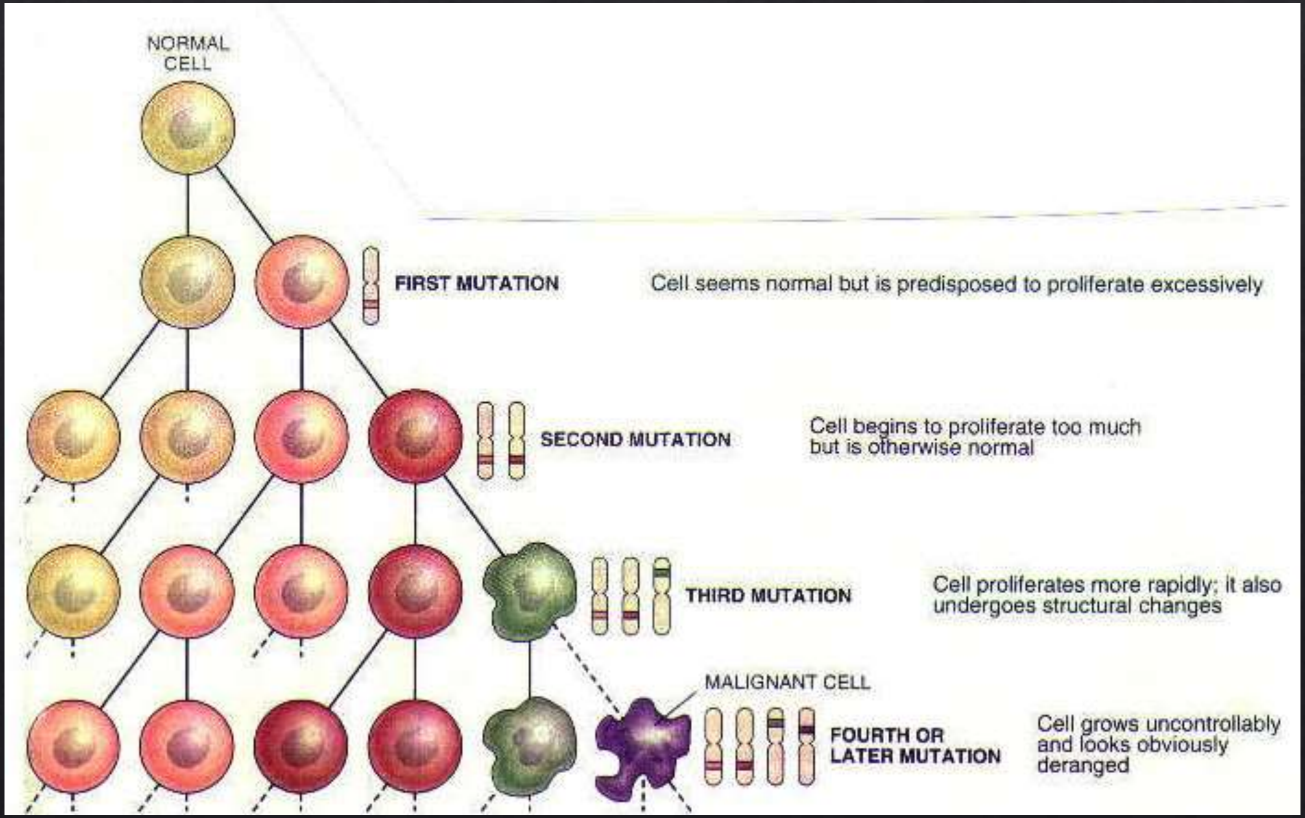




http://srag.jsc.nasa.gov/SpaceRadiation/Why/Why.cfm

Radiation Effects on Cells

- DNA mutations are passed along to subsequent cell lines, ultimately resulting in malignant (cancer) cells



Radiation Protection

- Hierarchy of controls:
  - Elimination:

    Don't be where the radiation is (avoid SAA, poles)
  - Engineering:

    Radiation resistant regions within ISS
  - Administrative:

    No EVA in SAA or during CME
  - PPE:

    Detection devices, shelter in place

ALARA

- As Low as Reasonably Achievable (ALARA)
  - A commitment to make all reasonable efforts to minimize exposure, hence reduce risk.
  - Part of the Legal limits. Just as important as the "Numerical limits"
- Why - Any exposure, no matter how small, results in a finite (albeit small) increase in subsequent cancer risk (no threshold theory)
  - "means making every reasonable effort to maintain exposures to radiation as far below the dose limits in this part as is practical consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest" (10CFR Part 20 §20.1003)

ISS Radiation Shielding

Well Shielded

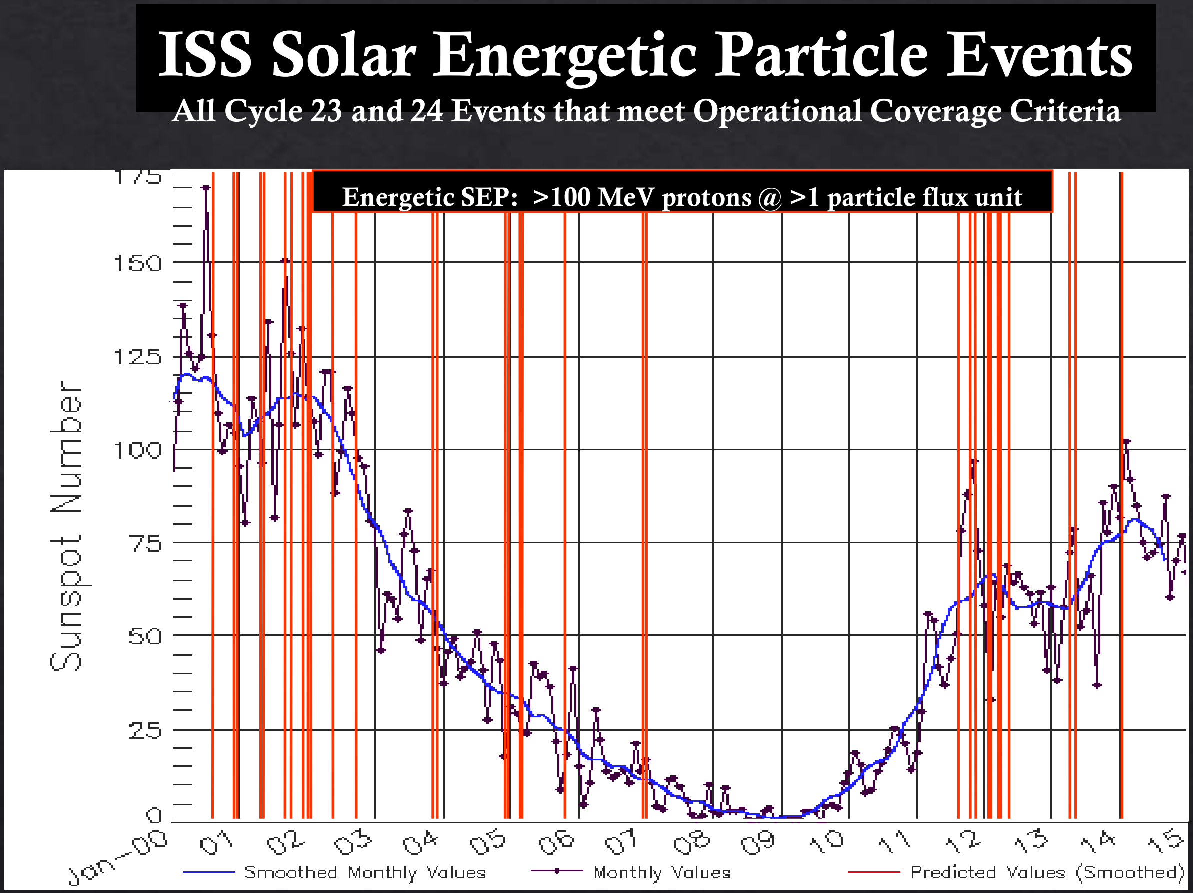
- Node 2 USOS Crew Quarters
- Service Module, aft of treadmill

Not Well Shielded

- Lab Window
- Cupula
- Airlocks
- Service Module, fore of treadmill (Russian crew quarters)

Radiation Protection

- SPE exposures to ISS crew have not been extreme:
  - significant protection by the geomagnetic field
  - Fortunate ISS location within the magnetic field during the most intense time of events.



US ISS Active Radiation Monitors

IV-TEPC, Intra-vehicular tissue equivalent proportional counter – New – two detector volumes

TEPC, tissue equivalent proportional counter

Top in lab with a piece of poly shielding to be used in the crew quarter.

Second is detector

third is spectrometer box

EV-CPDS, Extra-vehicular Charged Particle Directional Spectrometer – Located on STBD side of S-0 truss – Zenith rail. Apertures are forward, behind and Zth

Tissue Equivalent Proportional Counter

- Shuttle and ISS (intravehicular)
  - Omni-directional
  - Contingency evaluation, trend analysis, model validation

Dosimeters

- Passive Radiation Dosimeter (PRD)
  - ISS - Radiation Area Monitors (RAM)
  - Trend analysis, model validation
- ISS - High Rate Dosimeters (HRDs) only
- Trend analysis, model validation, contingency evaluation

Charged Particle Directional Spectrometers (Internal)

- Real-time time-resolved measurements, model validation, contingency evaluation
- Single axis internal unit

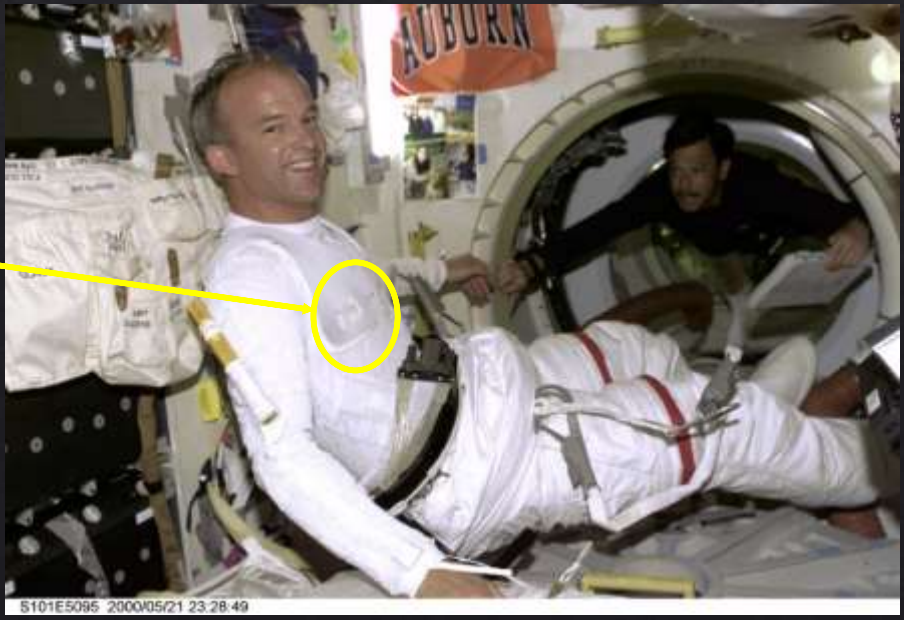
Charged Particle Directional Spectrometers (External)

- Real-time time-resolved measurements, model validation, contingency evaluation
  - Three axis external unit
  - +X, -X, -Z fixed station axes

Crew Passive Dosimeters (CPD)

- Records legal dose
- Worn IVA and EVA
- Thermo-Luminescient dosimeters (TLD) (dose)
- CR-39 (LET)

One of our astronauts proudly modeling his crew dosimeter in the EVA suit liquid cooling garment



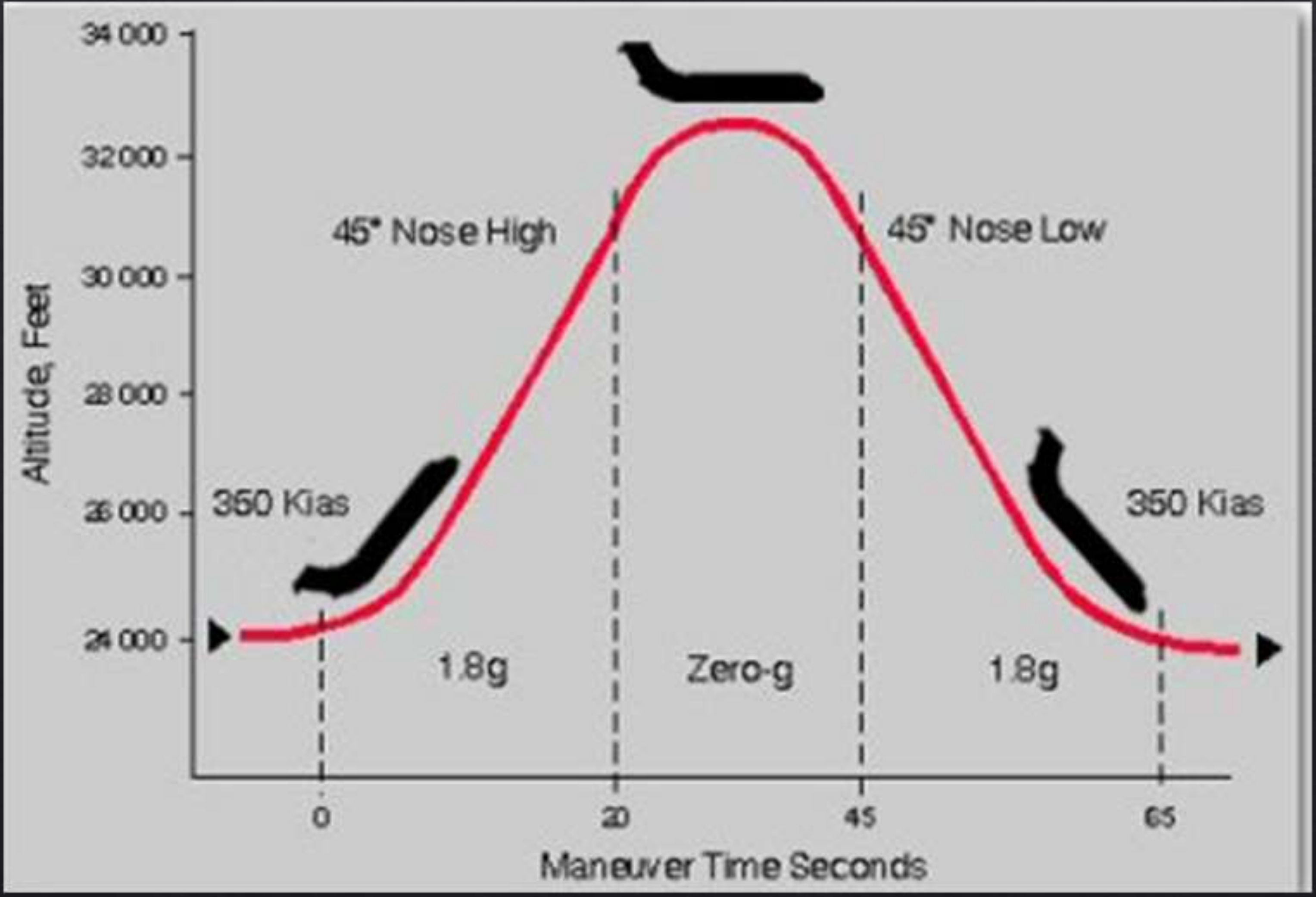
Spacecraft Environment

Reduced Gravity

"Weightlessness is often misrepresented as a physiologically challenging condition but is more accurately described as an absence of the accustomed physiological challenges with respect to the gravity vector"
– Barratt & Pool, Principles of Clinical Medicine for Space Flight

- Absolute effects on the human body are not known
  - Combined effects of microgravity, deliberate exercise countermeasures, environmental parameters, etc.
  - Standard investigative and diagnostic methods are often not available
  - Limitations in launch mass/volume/power, storage, fluid handling techniques, crew time
  - Sample size remains small (543 people in earth orbit)

Reduced Gravity



Is the ISS in "zero G"?

Location	Gravity due to			Total
	Earth	Sun	Rest of Milky Way	
Earth's Surface	9.81 m/s^2	6 mm/s^2	200 pm/s^2 = 6 mm/s/yr	9.81 m/s^2
Low Earth Orbit (ISS)	9 m/s^2	6 mm/s^2	200 pm/s^2	9 m/s^2
200,000 km from Earth	10 mm/s^2	6 mm/s^2	200 pm/s^2	up to 12 mm/s^2
6 million km from Earth	10 $\mu m/s^2$	6 mm/s^2	200 pm/s^2	6 mm/s^2
3.7 billion km from Earth	29 pm/s^2	10 $\mu m/s^2$	200 pm/s^2	10 $\mu m/s^2$
Voyager 1 (17 billion km from Earth)	1 pm/s^2	500 nm/s^2	200 pm/s^2	500 nm/s^2
0.1 light-years from Earth	400 am/s^2	200 pm/s^2	200 pm/s^2	up to 400 pm/s^2

Micro Gravity

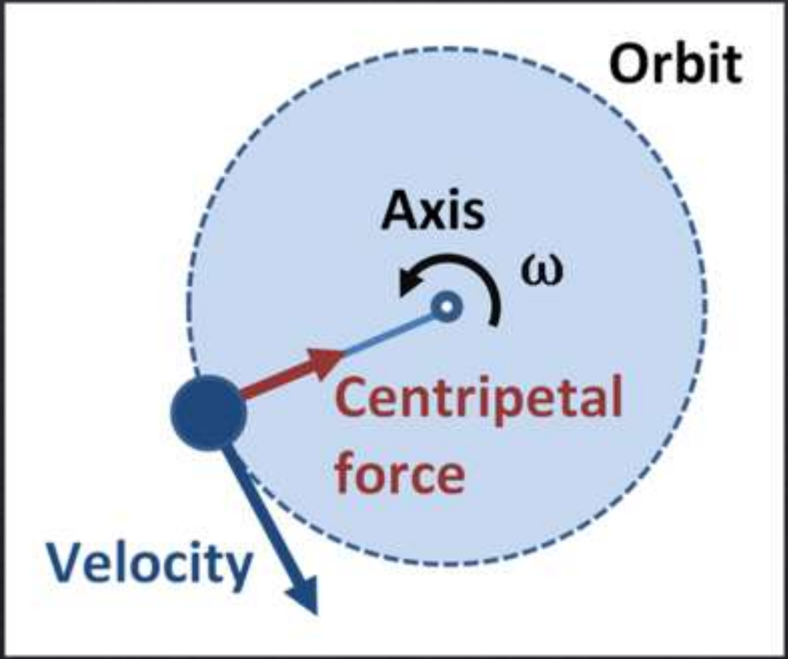
- If ISS isn't in "Zero-G", how do astronauts float?

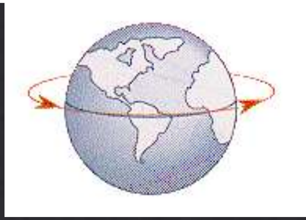
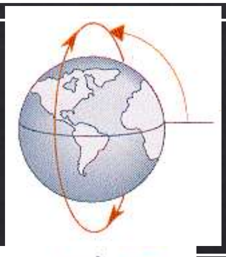
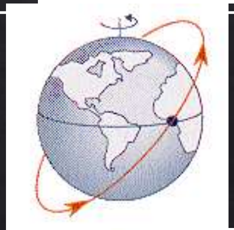
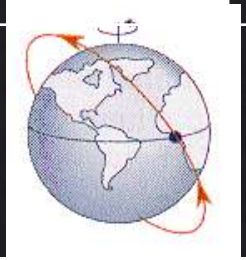
They don't…

they fall.

Quick Foray into Orbital Mechanics

- ISS doesn't "escape gravity"
- Microgravity aboard the ISS a result of freefall
  - The station is constantly falling 'over the horizon'
  - Its vectors oppose one another to prevent it from constantly accelerating

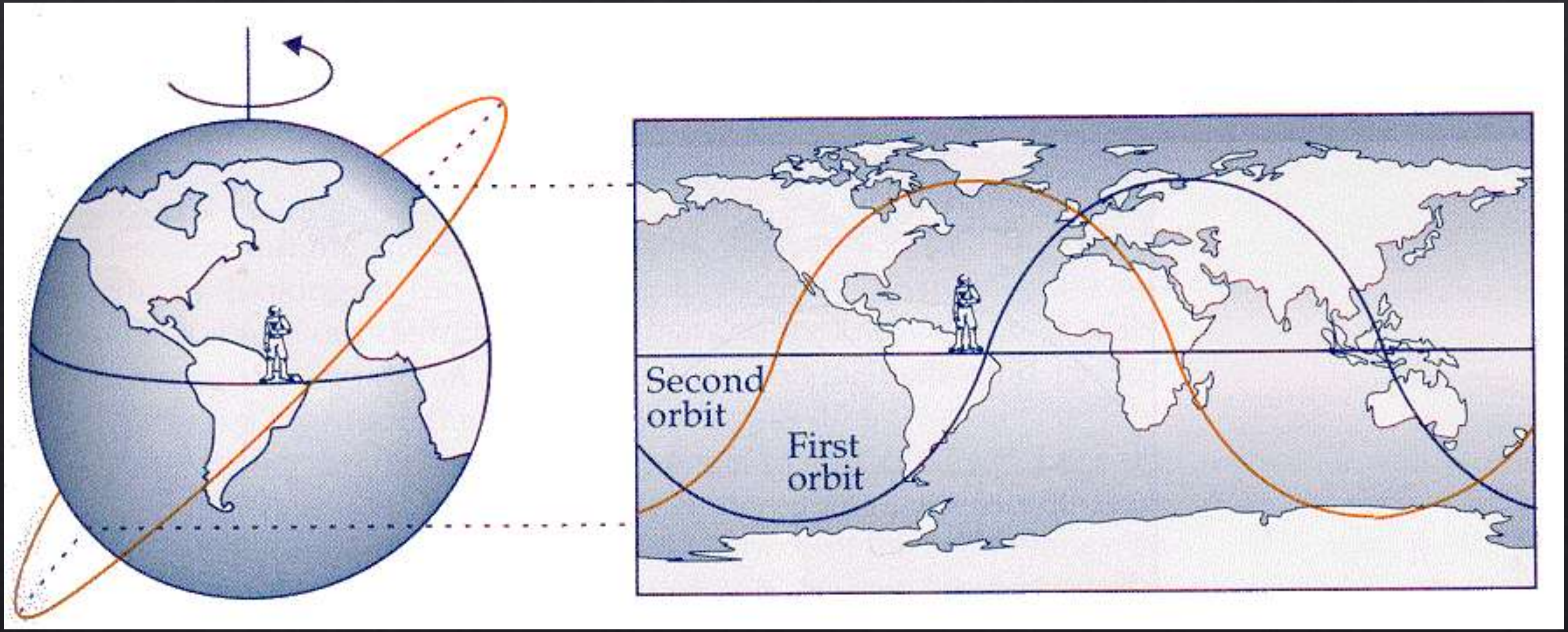


Inclination	Orbit Type	Diagram
0° or 180°	Equatorial	
90°	Polar	
$0^\circ \le I < 90^\circ$	Direct (Prograde)	
$90^\circ < I \le 180^\circ$	Indirect (Retrograde)	

Typical Orbits

Mission	Orbit Type	Semi-major axis	Period	Inclination	Other
-Communications -Early Warning -Nuclear Detection	Geostationary	42,158 km	24 hr	$\sim 0^{o}$	$e \approx 0$
-Remote Sensing	Sun-synchronous	~6500-7300 km	~90 min	$\sim 95^{o}$	$e \approx 0$
-Navigation -GPS	Semi-synchronous	26,610 km	12 hr	55^{o}	$e \approx 0$
-Space Shuttle	Low-Earth Orbit	~6700 km	~90 min	$28.5^{o} – 57^{o}$	$e \approx 0$
-Communications -Intelligence	Molniya	26,571 km	12 hr	63.4^{o}	$\omega = 270^{o}$ $e = 0.7^{o}$

Ground Track



Ground Tracks